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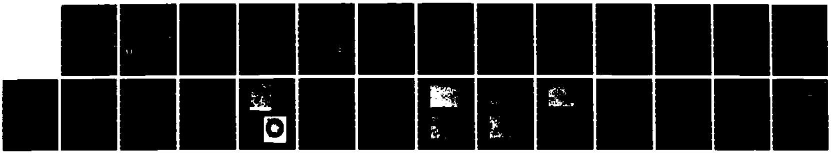

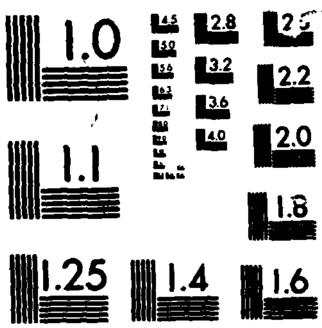

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MECHANICAL PROPERTY DEVELOPMENT IN HOT ISOSTATIC PRESSED (HIP) LOW ALLOY STEEL POWDER

PETER THORNTON

JOHN SENICK

JOHN ATCHINSON

JANUARY 1986

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
CLOSE COMBAT ARMAMENTS CENTER
BENÉT WEAPONS LABORATORY
WATERVLIET, N.Y. 12189-4050

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The mechanical properties of a low alloy steel gas atomized powder, which was hot isostatically pressed (Hipped) to full density, were developed using typical commercial heat treatment practices. Tempering temperatures were varied systematically from 1000°F to 1200°F and the tensile and impact properties evaluated along with the corresponding microstructural conditions. Yield strengths on the order of 180,000 psi accompanied by low temperature,

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20. ABSTRACT (CONT'D)

impact toughness values of 18-20 ft-lb were developed in billets of this material, 4 inches in diameter. The results of this study demonstrate that hot isostatic pressing of low alloy steel powder can be utilized to produce high quality components for critical applications which will benefit from near-net shape manufacturing techniques.

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INTRODUCTION

In the last two decades significant technical advances have been made for producing high-quality engineering alloys by the application of powder metallurgy (P/M) and hot isostatic pressing (HIP) techniques[1-7]. The use of P/M near-net shape processes has made it possible to substantially reduce the amount of machining required to make certain geometrically complex parts. In addition, other important considerations, such as conservation of raw materials and energy, plus reduced manufacturing time, have enhanced the desirability of utilizing HIP powder metallurgy techniques.

However, most of the HIP P/M developments to date have been concentrated on materials that are very expensive and difficult to fabricate. These materials include: tool steels, carbides, high temperature alloys (superalloys), and titanium alloys. Until recently, little work has been done on the application of HIP P/M to low alloy steel[8].

The object of this current investigation was to develop the mechanical properties of "hipped" low alloy steel powder and the attendant microstructural relationships using commercial heat treating practices. Accordingly, such information will be applicable and useful in the commercial production of components made from this material.

References are listed at the end of this report

PROCEDURE

Low alloy steel powder (4335 + V) as shown in Figure 1, was produced by vacuum induction melting and gas atomizing with nitrogen. Experimental billets, 4 inches in diameter, were made by hipping the powder in plain carbon steel cans.

The HIP process was conducted at 2000°F and 15,000 psi for 4 hours at temperature and pressure. The subsequent billet material was sliced into appropriate size disks as illustrated in Figure 2 and heat treated as follows:

1. Annealed at 1650°F for 1-1/2 hours and furnace cooled.
2. Austenitized at 1550°F for 1-1/2 hours and oil quenched.
3. Tempered at 50°F temperature increments between 1000°F and 1200°F for 1-1/2 hours.

The hardness of each disk was evaluated after tempering in order to establish a useful heat treatment guide for developing mechanical properties.

Subsequently, standard tensile and Charpy impact specimens were machined from the disks and the tensile properties evaluated at room temperature, while the Charpy behavior was evaluated at -40°F. The tested specimens were then examined in both the unetched and etched conditions for metallographic purposes.

RESULTS

The physical characteristics and chemical analysis of the powder are presented in Tables I and II. Examination of this data shows that the powder contains relatively low concentrations of contaminants such as phosphorous and sulfur, and also contains low amounts of dissolved gases: e.g., oxygen, hydrogen, and nitrogen. The as-hipped density of the steel was 0.283 lb/in^3, which is essentially 100% of the theoretical density for this alloy. The change in density due to thermal induced porosity (TIP) was also determined after hipping and ranged from zero to 0.20%. Therefore, TIP was considered negligible.

The mechanical property test results are summarized in Table III. Examination of this data shows that as tempering temperature was varied from 1000°F to 1200°F, the yield strength ranged systematically from 179,000 psi to 147,000 psi for a corresponding range of 42 to 34 hardness on the Rockwell "C" scale. These strength values were accompanied by Charpy impact values (at -40°F) ranging systematically from 18 ft-lb to 35 ft-lb. It should also be noted that the ductility as measured by %RA in the tensile test, was uniformly high (55-61%) indicative of a relatively clean, isotropic material.

Microstructural examinations performed on the mechanical test specimens reveal a material that occasionally contains small globular oxide inclusions as illustrated in Figures 3 and 4.

However, this material is basically very clean or inclusion free. Such an observation indicates that the liquid steel was not contaminated by low melting phases or tramp elements, and that subsequent powder production and handling was performed in a manner that precluded significant oxidation of the powder particles. Furthermore, no microporosity was observed during the microstructural examinations indicating that consolidation of the powder particles was, in essence, complete and that thermal induced porosity (TIP) was not produced during hipping. This latter feature corroborates the density determinations previously discussed under physical characteristics.

Etched microstructures representing the five tempering temperatures are shown in Figures 5-9. These structures consist of fine grained tempered martensite, indicative of a chemically uniform low alloy steel which has been properly heat treated. This type of microstructure has previously been associated with high strength and high toughness in both hipped atomized powder and high quality conventional forgings made from this alloy composition[9-11].

Grain boundary evaluations were also conducted on specimens from each tempering condition and revealed that the austenitic grain size in this material was consistently fine and uniform, ranging from 9-10 ASTM grain size number. A representative grain boundary condition is shown in Figure 10.

CONCLUSION

The results of this investigation demonstrate that high mechanical properties can be developed in this hot isostatically pressed, low alloy steel powder. Specifically, yield strength levels up to 180,000 psi were accompanied by very acceptable levels of low temperature, Charpy impact toughness - for example, 18-20 ft-lb at -40°F. Furthermore, these properties, which vary in a systematic manner, can be produced and controlled by typical commercial heat treatment methods readily available in both government facilities and private industry.

The microstructural evaluations corroborated the mechanical property response demonstrating that a low alloy steel, which contains very little non-metallic included matter and is relatively homogeneous in chemical composition, can be heat treated to high strength levels without producing unacceptably low values of impact toughness and ductility. Also, a systematic range of strength/toughness conditions can be produced by these heat treatments.

In conclusion, the procedures and subsequent results of our study demonstrate that gas atomized, low alloy steel powders, under the appropriate circumstances, can be processed into solid shapes exhibiting high values of strength and toughness. The appropriate circumstances include powder that is properly made

and handled, then hot isostatically pressed to a density on the order of 100% theoretical density for that alloy. Such a material will have potential for application to high quality, critical components and can be adapted to near-net shape production of complex geometry parts which ordinarily require substantial machining to achieve their final configuration.

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TABLE I

Physical Characteristics of Atomized Low Alloy Steel Powder

Screen Analysis

U.S. Standard Mesh	30	50	70	100	200	325
(μm)	(595)	(297)	(210)	(149)	(74)	(44)
% undersize	100	77.1	64.6	50.7	27.8	11.9

Tap density 0.201 lb./in^3 (71.1% theoretical density)

Flow rate (ASTM B213) - 15 sec.

TABLE II

Chemical Composition of Low Alloy Steel Powder

C	Mn	P	S	Si	Cr	Ni	Mo	V
.35	.66	.010	.006	.12	1.13	2.72	.47	.07

O	N	H	Fe
34ppm	100ppm	2.4ppm	bal.

* ppm - parts per million

TABLE III

Mechanical Properties of Hipped Low

Alloy Steel Powder*

Tempering Temperature (°F)	YS (10^3psi)	UTS	%El	%RA	Charpy Impact @-40°F	Hardness(R_c)
1000	177-179	192	16	57	18-20	42
1050	169	184	16-17	55-58	24-26	41
1100	162	175	18	58	24	39
1150	151-152	162	18	60	29-30	36
1200	147	156-157	18-19	61	34-35	34

* Two specimens for each condition

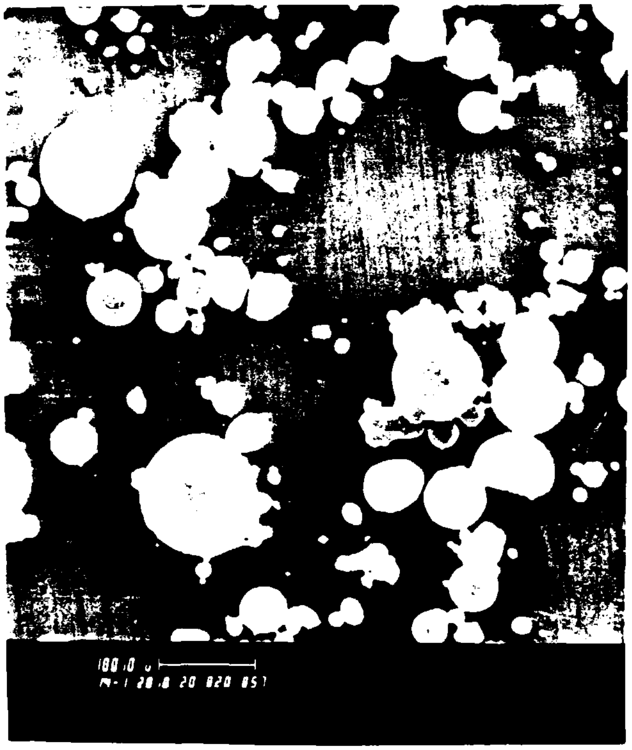

FIG. 1(a) - SEM micrograph of gas atomized low alloy steel powder showing particle morphology and size distribution. 140X

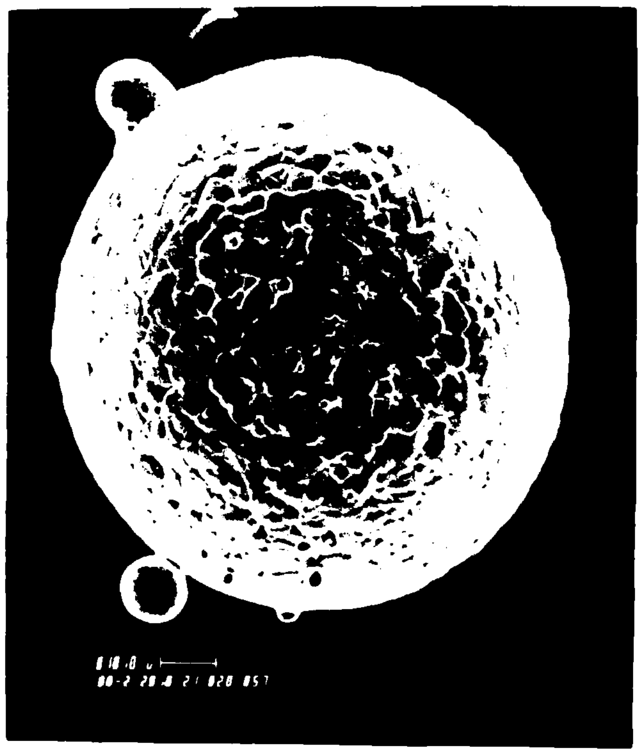

FIG. 1(b) - SEM micrograph of a typical spherical powder particle displaying satellites and solidification features on surface. 850X

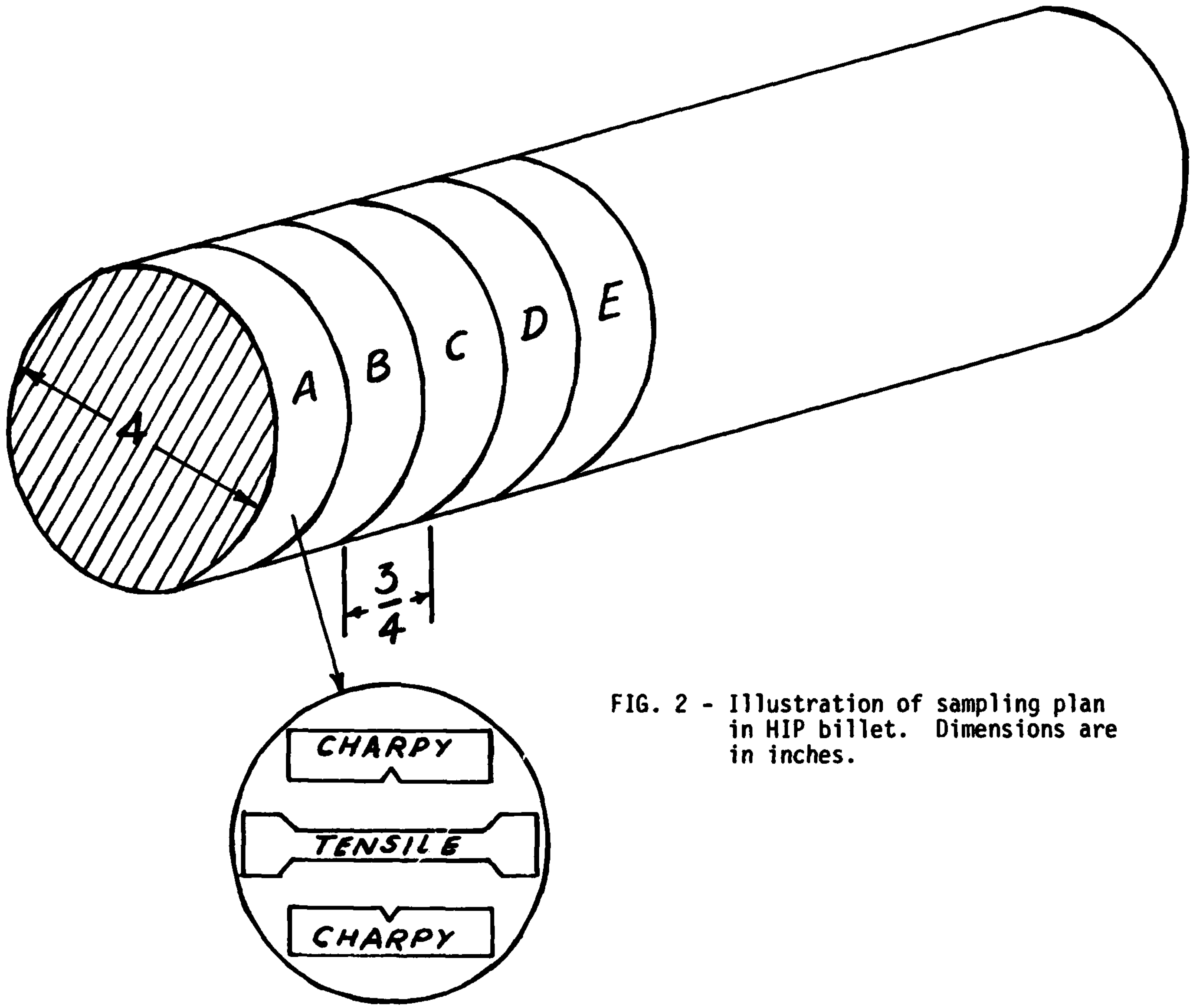

FIG. 2 - Illustration of sampling plan in HIP billet. Dimensions are in inches.

FIG. 3 - Unetched photomicrograph showing the typical nonmetallic inclusion content in the Hipped material.
100X

FIG. 4 - Unetched photomicrograph illustrating the nature of occasional oxide type inclusions in the Hipped billet.
100X

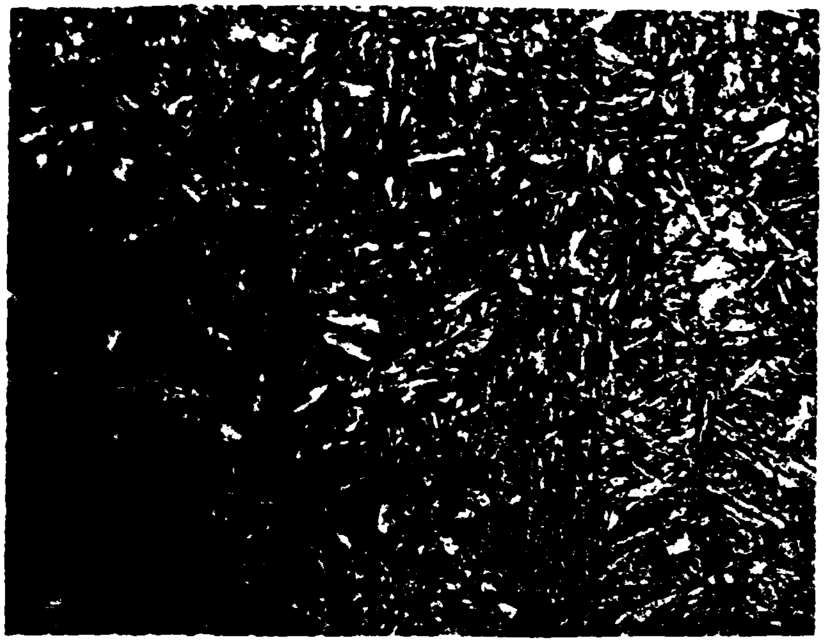

FIG. 5 - Microstructure of Hipped Low Alloy steel powder tempered at $1000^{o}F$.

1000X

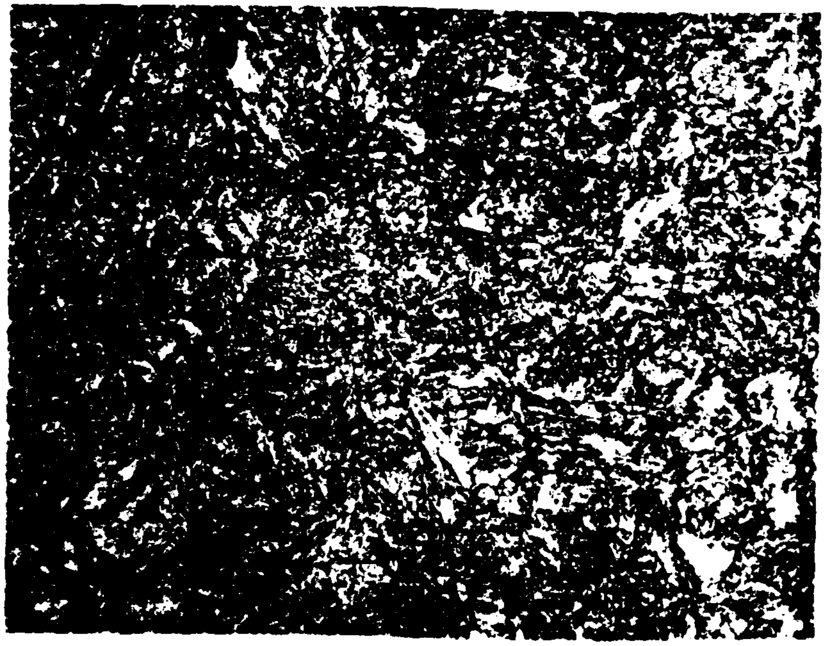

FIG. 6 - Microstructure of Hipped Low Alloy Steel Powder tempered at 1050°F.

1000X

FIG. 7 - Microstructure of Hipped
Low alloy steel powder
tempered at 1100°F.

1000X

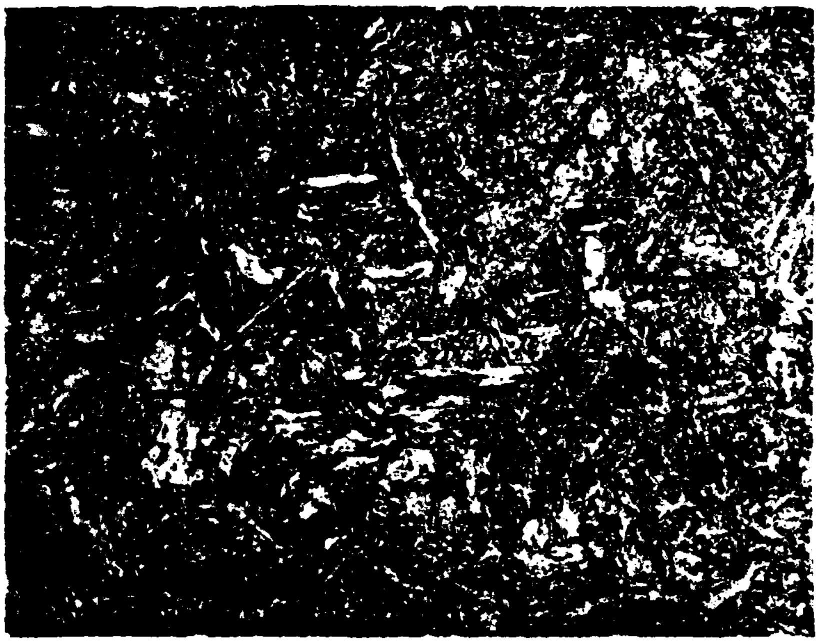

FIG. 8 - Microstructure of Hipped
low alloy steel powder
tempered at 1150°F.

1000X

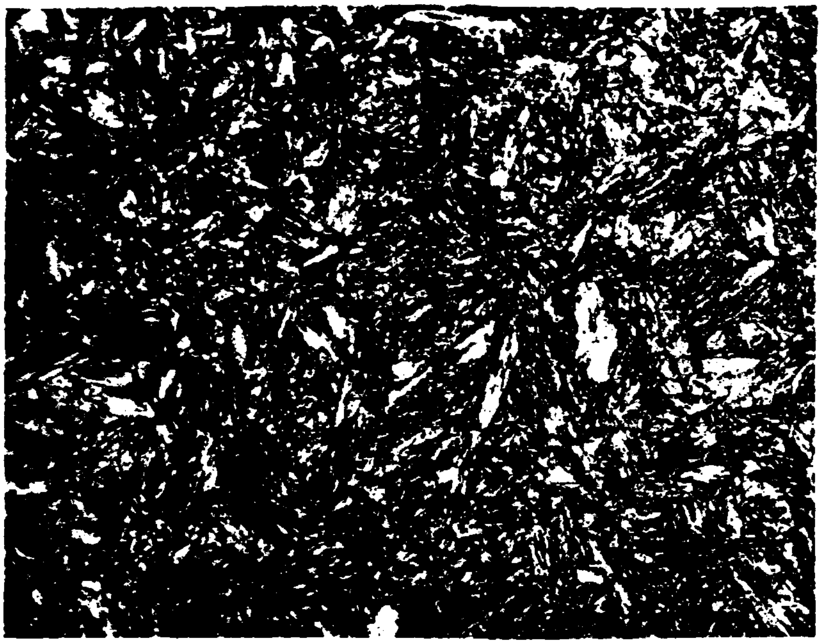

FIG. 9 - Microstructure of Hipped low alloy steel tempered at 1200°F. 1000X

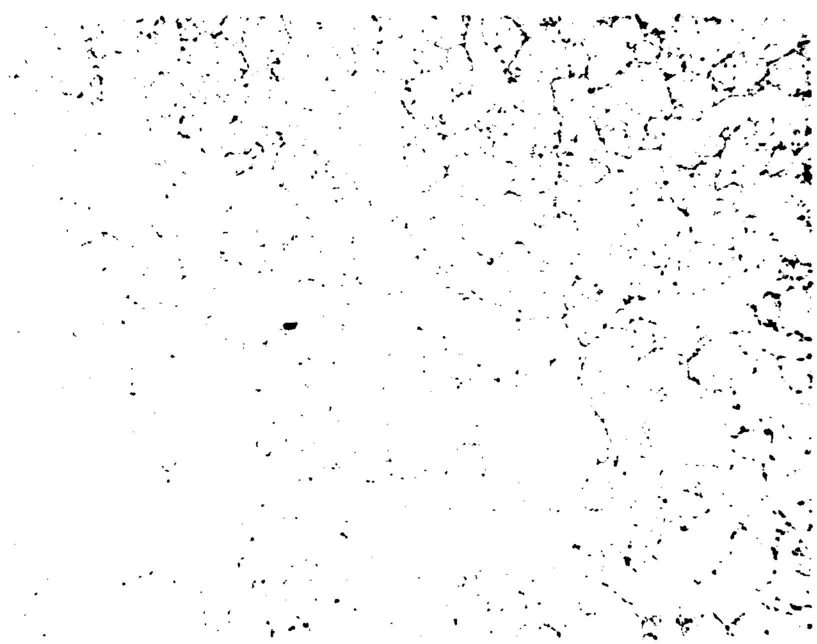

FIG. 10 - Photomicrograph showing the typical prior austenitic grain size in the heat treated disks. Average ASTM G.S.# = 9.8. 500X

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